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Publication date
2025

Document Version
Final published version

Published in
Book of Abstracts 44th Benelux Meeting on Systems and Control

Citation (APA)
van Meer, M., van Meijel, T., van Halsema, E., van Halsema, E., Witvoet, G., & Oomen, T. A. E. (2025). Flexible Feedforward Control of Piezo-Stepper Actuators. In R. Carloni, J. Alonso-Mora, J. Dasdemir, & E. Lefeber (Eds.), *Book of Abstracts 44th Benelux Meeting on Systems and Control* (pp. 137-137). Rijksuniversiteit Groningen.

44^{th} Benelux Meeting

on

Systems and Control

March 18 – 20, 2025

Egmond aan Zee, The Netherlands

Book of Abstracts

The 44^{th} Benelux Meeting on Systems and Control is sponsored by

disc dutch institute of systems and control

Raffaella Carloni, Javier Alonso-Mora, Janset Dasdemir, and Erjen Lefeber (Eds.)
Book of Abstracts - 44^{th} Benelux Meeting on Systems and Control

University of Groningen
PO Box 72
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ISBN (PDF without DRM): 978-94-034-3117-8

Flexible Feedforward Control of Piezo-Stepper Actuators

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1 Background

Accurately controlling piezo-stepper actuators is complicated by mechanical misalignments and rate-dependent hysteresis, both of which degrade positioning performance. In these actuators, expansions and retractions of piezoelectric elements are converted into a long-range walking motion, see Fig. 1. They are attractive in high-precision stages [1], but these challenges often limit accuracy.

2 Problem Formulation

The piezo displacement dynamics can be expressed as:

$$\dot{y}(t) = M\big(\dot{u}(t), u_a(t)\big)\,\dot{u}(t), \tag{1}$$

where $y(t)$ is the displacement, $u(t)$ is the applied voltage, and $u_a(t)$ is the voltage absement that captures hysteresis. The aim is to design a feedforward control law $u(t) = f(r(t), q)$ for accurate tracking of any reference $r(t)$.

3 Control of Piezo-Steppers

A two-step feedforward design is considered. First, a hysteresis model $\hat{M}$, identified from data, is used to ensure that

$$u(t) = \hat{M}^{-1}(\dot{u}(t - T_s), u_a(t))\,\dot{r}(t) \tag{2}$$

compensates rate-dependent hysteresis. Next, a position-dependent correction is iteratively learned to compensate for mechanical misalignments. This approach retains accuracy across different step frequencies, leading to task flexibility.

4 Results

A significant reduction in position error is observed when compared to traditional feedforward. Figure 3 confirms that hysteresis compensation alone improves accuracy, while the additional misalignment compensation yields the best performance.

5 Conclusion

A feedforward control strategy for piezo-stepper actuators is presented. By addressing both hysteresis and misalignments with data-driven modeling and iterative compensation, this approach achieves precise positioning over a wide range of reference velocities with low computational complexity. Ongoing research focusses on implementing this solution in a closed-loop setting.

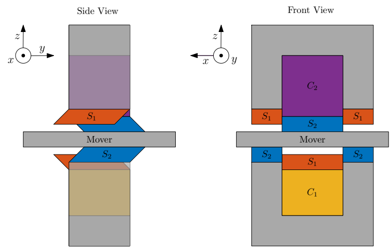

Figure 1: Schematic overview of a piezo-stepper actuator. The clamps (C_1, C_2) press the shears (S_1, S_2) onto the mover. When a shear is in contact with the mover, it contracts or expands laterally to push or pull the mover.

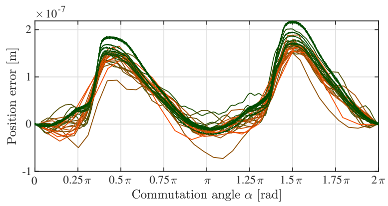

Figure 2: Mechanical misalignments cause a repeatable position error for both low (—) and high (—) step frequencies

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[1] Jianping Li, Hu Huang, and Takeshi Morita. Stepping piezoelectric actuators with large working stroke for nano-positioning systems: A review. *Sensors and Actuators, A: Physical*, 292:39–51, 2019.

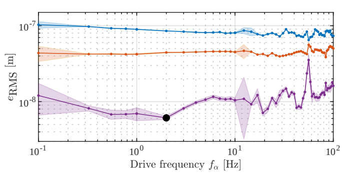

Figure 3: Traditional feedforward control (—) leads to large error. Hysteresis compensation (—), combined with misalignment compensation (—) improves performance by an order of magnitude.